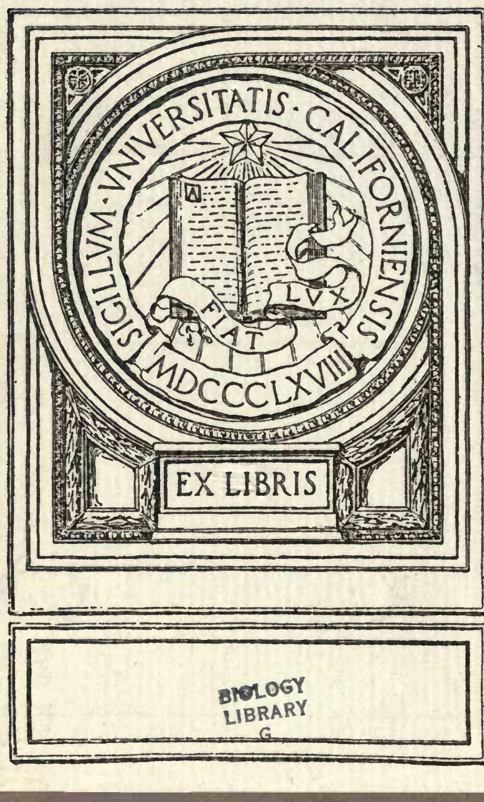
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MUSCULAR STRENGTH AND MUSCULAR SYMMETRY IN HUMAN BEINGS

II. In Adult Males

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Determinations of muscular strength in human beings by means of dynamometers have been made in large numbers by numerous investigators in connection with various problems (1). Among the problems so approached may be mentioned studies of fatigue (2) and of relationship between physical strength and intelligence (3). The favorite instrument in these studies has been the grip dynamometer, either the old form of Collin or the improved type designed by Smedley (1). In spite of the objections that have been urged against the grip dynamometer as an instrument of research, much valuable information has been obtained with its aid (1). It presents, however, the undoubted shortcoming of making use of one of the most complex musculatures of the body and a musculature, moreover, which receives much special training. The question may properly be raised whether the strength of the grip truly represents general bodily strength or whether this particular musculature may not reflect special conditions to an exceptional degree. A test of strength, to be quite satisfactory, should afford information of the strength of the body as a whole. Ideally it should include all the important muscle-groups; practically a strength test is valid if proof can be furnished that it constitutes a fair sample of the entire strength.

The system of muscle-testing in course of presentation in the series of papers of which this is the second (4) differs from the systems previously proposed in the fundamental fact that it measures "breaking strength" of muscles, namely, the force required to overcome maximal resistance rather than the utmost positive effort, as in other methods. Which system is better can be determined finally only by continued experience and comparison. Certain advantageous features of the

present system may be mentioned. As a routine feature of the test the subject is required to develop resistance at the command "hold back" uttered sharply. We find that under this stimulus the maximum effort is elicited, almost as a reflex. Only by deliberate planning on the

TABLE 1

Average percentage distribution of strength among the muscles, adult males. For comparison the distribution for children of 13 to 18 years is given also

MUSCLE-GROUP	ADULT MALES	13 TO 18 YEARS
Feet		
Plantar flexion	10.00	9.30
Dorsal flexion	2.85	3.20
Inversion	1.90	2.10
Eversion	1.80	2.00
Thighs		
Adduction	1.50	1.55
Abduction	1.40	1.50
Extension	3.70	3.00
Flexion	3.20	3.10
Knees		
Extension	3.30	3.30
Flexion	1.75	1.70
Shoulders		
Pectoralis	2.35	2.10
Latissimus dorsi	1.70	1.45
Anterior deltoid	2.10	2.00
Posterior deltoid	1.40	1.50
Forearms		
Extension	1.50	1.60
Flexion	2.25	2.50
Wrists		
Extension	1.05	1.35
Flexion	1.35	1.90
Fingers		
Extension	0.65	0.70
Flexion	2.95	2.75
Thumbs		
Adduction	1.30	1.40

part of the subject will less than his best effort be put forth. Thus an element of reliability is introduced, which is of the highest importance. As a matter of fact the deliberate attempt to make an inferior showing is instantly revealed in the changed character of the response. Since the spring balance with which the strength is determined is held in the

hands of the operator, the line of pull can be rectified in accordance with the position of the subject. The maintenance of correct lines of pull is of course essential to the validity of any system of strength-testing. The promptness with which the correct position can be taken is a feature of this method which becomes valuable as a saver of time when large series of tests are being carried on.

The muscle-test. The system of muscle-testing as originally developed is described elsewhere (5). The list of muscles included in the complete test is set down in table 1. For the series of tests on adults on which this paper is based certain muscle-groups were regularly omitted. These were *a*, the plantar flexors, which are so strong in adults as to make their testing a matter of inconvenience, since a lever has to be arranged for multiplying the force of the spring-balance pull; *b*, the finger extensors, which were omitted because their short leverage requires the substitution of a special narrow sling for the full-width sling used with the other muscle-groups, a time consuming substitution, and in this particular series the saving of time was an important consideration. Tests of finger flexors were made on only part of the subjects. Here the short leverage, together with the great strength, marks the group as less satisfactory than most of the others. Tests of the wrist flexors were omitted from part of the early subjects on account of a fear, found later to be unjustified, that testing them might give discomfort.

Subjects. The adults tested were students or instructors in this University. For assistance in obtaining the coöperation of these individuals we are indebted to the Department of Military Training of Stanford University, for whose courtesy we wish to express our thanks. In addition to the fifty adult males on whom the report is primarily based, we had access to the records of an equal number of adult females tested by Doctor Mosher and one of us (6). There were also available the records of fifteen adults from the series of infantile paralysis cases reported in a former paper (4), and more than a hundred "short" tests (p. 34) made from time to time as opportunity offered. In many cases duplicate records were made at least eight hours apart; about one-fourth of the subjects were tested five or more times.

Object of the experiments. Our object in these experiments was in part the establishing for adults of the constants previously worked out for children (4). In addition to this, however, we had in mind the possibility that this system of testing might offer certain advantages for the routine determination of strength provided it could be shown to be scientifically reliable and practical in application.

The complete test, as outlined in table 1, can scarcely be carried through in less than a half-hour. Clearly, for practical purposes, some abbreviation is highly desirable. A feasible method of abbreviation would be to make actual determinations of strength of a few muscle-

TABLE 2

Coefficients of correlation, individual muscle-groups to total strength, 56 adults

MUSCLE-GROUP	COEFFICIENT OF CORRELATION	
	Right	Left
Feet		
Plantar flexion		
Dorsal flexion	0.86	0.83
Inversion	0.68	0.66
Eversion	0.73	0.66
Thighs		
Adduction	0.815	0.81
Abduction	0.885	0.89
Extension	0.93	0.87
Flexion	0.89	0.875
Knees		
Extension	0.83	0.865
Flexion	0.87	0.93
Shoulders		
Pectoralis	0.92	0.87
Latissimus dorsi	0.73	0.76
Anterior deltoid	0.77	0.79
Posterior deltoid	0.59	0.64
Forearms		
Extension	0.825	0.82
Flexion	0.89	0.91
Wrists		
Extension	0.61	0.585
Flexion	0.60	0.64
Fingers		
Extension		
Flexion	0.47	0.50
Thumbs		
Adduction	0.80	0.78

groups only and to compute from these the total strength. That such a method is valid is suggested in a former paper (Martin: loc. cit., p. 72). Our task here is to verify the validity of this idea and to examine the different muscle-groups individually to see which should be included in the abbreviated test. Since the first criterion of an abbreviated test

must be its reliability, namely, the showing that it represents fairly the total strength, the muscles selected for inclusion should be those that show the highest correlation of individual strength with the total strength, provided the muscles are found to differ in this regard.

For comparing the strength of individual muscles with the total strength of the body we used a series of fifty-six cases on which complete tests (except of plantar flexors and finger extensors, as noted above) had been made. Records of wrist flexion and of finger flexion were missing also from a part of the cases. These cases were tabulated and the Pearson coefficient of correlation of each muscle with the total strength calculated. The results are set down in table 2. Inspection of this table shows that the muscles vary among themselves in the extent to which their individual strength tends to bear a fixed relation to the total strength. There are ten pairs in which the correlation of each muscle of the pair with the total strength is above 0.80, with a probable error of not to exceed ± 0.032. Evidently a short test will be most reliable if selected from among these ten pairs of muscle-groups. Incidentally it may be noted that the lowest coefficients of correlation in the entire series were given by the finger flexors, which are the muscles used in tests of strength with grip dynamometers. It is probable that these coefficients are lower than would be given by tests taken with perfected instruments of the Smedley type, but the fact which seems to be generally true, to judge from table 2, that the muscle-groups with short leverage correlate less closely than do those with long leverage, indicates that the original selection of the grip as a criterion of bodily strength was perhaps unfortunate.

In making selection for a short test from among the ten pairs of muscle-groups whose correlations with total strength are satisfactorily high, the determining criterion would seem to be altogether that of suitableness for the practical procedure of the test. The application of this criterion narrows at once the range of selection. Thus hip extensors, hip flexors and knee extensors, although correlating well with total strength, are undesirable from the practical standpoint because they are very strong muscles, requiring often a tension of two hundred pounds or more to overcome their resistance, and the great labor involved in developing this high tension repeatedly is likely to prove too exhausting to the giver of the tests. The knee flexors are among the most satisfactory muscles tested on children, but with adults they are likely to cramp when contracted forcibly, a fact which constitutes a valid objection to their use in a routine test. There remain in the

available list six pairs of muscle-groups, three on the legs: dorsiflexors of the foot, adductors of the thigh, abductors of the thigh; and three on the arms: pectorals, extensors of the forearm, flexors of the forearm. Minor considerations suggest the elimination from the short test of the dorsiflexors of the foot and the extensors of the forearm: the first because removal of the shoe would be necessary, the second because testing of the forearm extensors involves a degree of care in placing the parts in position which militates against speed in carrying out the test. With the idea that the test might be found available in industrial studies we have striven to reduce the time required to the least possible figure. The four pairs of muscle-groups now included in the list are the adductors and abductors of the thigh, the pectorals and the flexors of the forearm. Without any real justification but merely from a feeling that the muscles which move the hand ought to have representation in the short test, we added originally to this list the flexors of the wrist. Additional experience has convinced us, however, that the added information thus obtained is not of sufficient importance to justify the additional time consumed in testing the wrist muscles; we omit them, therefore, from our standard short test as here proposed.

For the sake of completeness, and also in order that simple directions may be readily available, the technique of the short test is here outlined.

Apparatus required. An ordinary flat-face spring-balance with a scale capacity of 200 pounds by 2 pounds, equipped with a self-registering index. (There are scales on the market with self-registering indices but these are heavier than desirable. We have found it satisfactory to fit up an ordinary scale in our own shop with a simple device.) A stout wood handle is attached by a swivel to the upper end of the scale, and a loop of stout leather 1¼ inch wide and 30 inches in circumference is attached by another swivel to the lower end of the balance.

A stout table 6½ feet long and 2½ feet wide, with a cleat secured firmly across one end. A cushion on which the subject's head may rest should be provided with this table,

An upright post 4 inches square and at least 6½ feet high, so placed that it is surrounded on at least three sides by ample space. Some form of hand-hold is provided by which the subject may steady himself as he leans against the post. (A knotted rope tied to a convenient ring near by answers well for this hand-hold.)

Procedure: General instructions. The individual to be tested is referred to as the subject. The persons giving the test are: first, the adjustor; second, the operator.

The duties of the adjustor are to place the loop in the assigned position about the arm or leg, support it there with one hand and, if necessary, the arm or leg of the subject with the other. He gives the command "hold back" to mark the beginning of the pull, and "stop" to mark the end.

The operator has the handle of the balance in his right hand and the body of the balance in his left.

After the loop is adjusted the adjustor gives the command "hold back." At this command the subject contracts with all his power the muscle-group being tested and simultaneously the operator pulls upon the spring-balance. Tension must be developed as rapidly as possible *without jerking*, and must be increased until the resistance of the subject is actually overcome. At the command "stop" the pull is discontinued immediately. The scale is read at once and the reading recorded by the assisting clerk. The sliding indicator of the scale must always be returned to the zero position immediately.

Tests are taken with the subject fully dressed.

Muscle-groups that are reported by the subject to be sore are not tested.

Calculation of total strength. The sum of the strengths shown by the individual muscles included in the short test constitutes 15 per cent of the entire strength as found by the complete test (see table 1). To calculate the entire strength, therefore, the sum of these determined strengths must be multiplied by the reciprocal of 0.15, which is 6.67. The product thus obtained is the figure for the strength of the subject. If for any reason any muscle-group was omitted from the test, assume the strength of the omitted muscle to be the same as that of the corresponding muscle on the other side.

Detailed technique of the tests. a. Pectorals. The subject stands at attention with the middle of his back pressed firmly against the upright post and the hand of the arm not being tested grasping the hand-hold. The arm to be tested is allowed to be limp in the hands of the adjustor until the command "hold back," with which command the pectoral muscles are contracted as strongly as possible. The adjustor stands directly in front of the subject, facing him; places the loop of the balance about the arm to be tested, just above the elbow; with one hand he holds the loop in position and grasps lightly the subject's hand or wrist with his other hand. Keeping the subject's arm straight, the adjustor draws it across the subject's body as far as possible, keeping it as close to the body as can be done and still give clearance for the loop. At the command "hold back" the subject's effort is to hold the arm from being drawn backward and downward from this position. The operator, standing at the subject's side, holds the balance in a line downward and backward from the subject's elbow in such a position that the arm as drawn back will just clear the subject's body. At the command "hold back" the operator develops sufficient tension to draw the arm down to the side of the body. The command "stop" must be given and the pulling discontinued before the arm has been drawn beyond the vertical line.

b. Forearm flexors. The subject lies on his back on the table with his heels pressed firmly against the cleat. The adjustor stands at the subject's left for both flexors. His right hand holds the subject's elbow to the table; his left hand brings the subject's forearm into a position of flexion about 15 degrees toward the shoulder from the vertical, and adjusts the loop about the wrist so that its upper edge is at the crease in the skin at the base of the hand. The operator stands at the foot of the table; he develops tension at the word of command. The command "stop" should be given when the forearm reaches the vertical.

c. Thigh adductors. Position of the subject same as in the above test except that he presses against the cleat only with the foot of the leg that is not to be

tested. He may steady himself by grasping the edges of the table. The adjustor stands at the foot of the table; with one hand he places the loop in the hollow just above the malleolus (an equally correct index is to have the loop just clear of the top of an ordinary man's shoe); he seizes the subject's heel with the other hand; lifts the leg until the heel is just high enough to clear the other toe, and then draws the leg into extreme adduction. The toe of the leg to be tested must be kept vertical. The operator stands at the side of the table and develops tension at the word of command. The command "stop" should be given as soon as the leg is drawn into line with the axis of the body.

d. Thigh abductors. The position of the subject and of the adjustor is the same as in the above test. The loop is placed as for the adductors except that the direction of pull is opposite. The leg to be tested is drawn out 15 degrees beyond the line of the body; the effort of the subject at the command "hold back" is to prevent the operator from drawing the leg into line with the body. The command "stop" is given just as the leg reaches the midline.

The most convenient order for the tests is as follows:

Right pectoral
Left pectoral
Right forearm flexor
Left forearm flexor
Right thigh adductor
Left thigh abductor
Right thigh abductor
Left thigh adductor

Although the satisfactory giving of the test requires careful training and considerable practice on the part of operator and adjustor, the demands upon the subject are not great. We have made successful tests upon subjects with a very limited knowledge of English and only ordinary intelligence. Much time can be saved by letting subjects not yet tested see the test carried out on others. In this way they learn what is expected of them and carry out their part promptly when their turn comes. A few seconds over one minute is usually enough time for carrying out a short test.

Certain relationships which can readily be carried in mind are helpful in connection with the making of tests, especially where there is suspicion of malingering. Thus, as table 1 shows, pectorals and forearm flexors are of nearly equal strength, as are thigh adductors and abductors, and the former groups are slightly less than twice as strong as the latter. In men of ordinary strength pectoral and forearm flexors are likely to range between 75 and 100 pounds, and thigh adductors and abductors between 40 and 60 pounds. Of fifty-five adult males selected at random, 80 per cent of the muscles of the short test fell within these limits.

That the proposed short test is practicable we believe these observations demonstrate. That it gives a reliable picture of the entire strength can reasonably be assumed from the fact that each individual muscle-group included in the test correlates well with the entire strength. One would expect to find that the summed strength of these several muscle-groups would correlate with the entire strength even better than do the individual muscle-groups. That this is the case was shown by a comparison, on the same series of adults on which the correlation of individual muscles were worked out, of the summed strength of the muscles of the short test with the entire strength. The coefficient of correlation of this comparison was 0.94 ± 0.01. So high a correlation constitutes sufficient demonstration that the short test is a reliable indicator of the entire strength.

Although the expression "entire strength" as here used applies actually only to that part of the strength represented by the muscle-groups of the complete test as outlined in table 1, these observations show that in all probability the real "entire strength" bears a fixed relationship to the strength of the muscles included in the complete test and also, therefore, to the short test. The principle of "random sampling" applies here. The muscle-groups included in the complete test constitute a fairly large sample of the whole musculature. Individual muscles and small groups of muscles correlate well with the summed strength of the complete-test (see above, also Martin: loc. cit., p. 72). There is no physiological or statistical principle that would justify any other assumption than that the muscle-groups not included in the complete test correlate equally well with it and with each other.

Muscular symmetry. In the first paper of this series (4) the distribution of strength among the muscles of the body in children was shown to vary somewhat with age so that three distinct age-groups could be established (loc. cit., p. 71). The symmetry of individuals was shown to deviate from the ideals as set down in the table by varying amounts, averaging for the entire series 16.7 per cent (loc. cit., p. 79, table). Application of the method there described to the present series of adult males gives the figures for percentage strength distribution that are presented in table 1 of this paper. These figures are averages of sufficient data except for plantar flexion and finger extension; the observations on which those values were obtained are fewer than desirable. Considerable errors in these two values would affect the others of the series only slightly, however, and it is felt that they are sufficiently close approximations for present purposes.

The deviations of individuals from ideal symmetry are decidedly less in this series of adult males than in the series of children presented in the former paper. The average mean deviation for this series is 10.7 as compared with 16.7 for the former. In fact, the greatest deviation in this series, a deviation of 16.5, is less than the average for children. We were quite unprepared to find adults more symmetrical as a class than children and are inclined to think that we may have happened upon an exceptionally symmetrical group. Most of them were college undergraduates and engaged at the time when these tests were being made in intensive military training.

The relation of strength to weight. A point on which stress was laid in the former paper (4) was that the ratio of strength to weight in children tends to be constant. That the same would hold for adults seems unlikely, chiefly because so many other factors in addition to weight become operative in adults in determining strength. In the former paper (p. 74) mention was made of the fact that boys of seventeen and eighteen years show higher strength-weight ratios than do younger boys, showing the beginnings of departure from the childish condition and suggesting the incidence of additional factors.

For a study of the relation of strength to weight we had available a series of one hundred and twenty-two adult males. This included our Stanford instructors and students, a few cases from the infantile paralysis series mentioned above, and a number of recent army recruits that we were enabled to test through the courtesy and coöperation of various army officers. The group as a whole would be considered as made up of outdoor men. The Stanford students, as previously noted, were most of them taking intensive military training. The weights ranged from 107 to 196 pounds, averaging 146.6. The strengths ranged from 2000 to 5800 pounds, averaging, in round numbers, 3900. (A single individual, the college strong man, weighing 208 pounds, made a strength record of 7600 pounds. This is so far in excess of our other records that we do not include it among our averages). The ratios of strength to weight ranged from 19 to 37, averaging 26.6. We are inclined to think that our figures for average strength and average strength-weight ratio are somewhat higher than they would be for adult males in general.

As would be expected, there is a moderate correlation between strength and weight, the coefficient for this series being 0.58 ± 0.04. This accords with the familiar fact that on the whole large men are stronger than small men. The correlation is not close enough, however, to

indicate that with adults, as with children, the body-weight is the dominant factor in determining strength. Whipple (loc. cit., p. 114) cites observations of correlation between strength and weight, in which strength was tested by a different method, with the following results: at Oxford, coefficient of correlation 0.46; at Cambridge, coefficient of correlation 0.56.

The significance of the strength-weight ratio. Where two individuals of equal weight differ widely in strength there are evidently at least four factors which may have influence in accounting for the difference. The first of these is actual amount of muscular tissue. There are undoubtedly considerable variations in the amounts of muscle substance present in the bodies of persons whose total weight is the same. A second factor is bodily configuration. It is quite conceivable that certain configurations lend themselves more favorably to effective exhibitions of muscular power than do others. Information on this point is lacking although it should be stated that in respect to the factor of height as an element in bodily configuration we have not been able to secure any evidence that it has significance. In investigating this point we grouped all our cases according to weight, using group intervals of five pounds, and then arranged all the members of each group in ascending order of height. We then examined the distribution of the strongest and next strongest members of each group with relation to height, and similarly of the weakest and next weakest. We found, however, nothing significant. One-half the strong were among the short men and the other half among the tall. Substantially the same distribution appeared also among the weak. Furthermore, the average strengths of the short and tall halves of each group were virtually equal.

A third factor is muscle-quality, and this undoubtedly has much to do with determining the strength. The fourth factor we may call, for lack of a better term, innervation. There can be little doubt that individuals vary in the extent to which they are able, by volition, to elicit muscular effort. That the usual manifestations fall far short of the potential maximum is shown by the familiar effects of excitement, as in the "strength of desperation." We have been at pains in the development of our procedure to avoid introducing the factor of excitement. The attempt has been to base the showing upon a maximal volitional effort made rather as a matter of routine than as a feature of competition or of desire to establish a record. Our feeling has been that a maximum effort made in "cold blood" gives a more uniform, and probably also a truer picture of the neuro-muscular power than would

a similar effort made under the stimulus of excitement. On the whole, muscle quality and innervation seem to us the factors most likely to dominate in the determination of strength, and in accordance with this view we are inclined to interpret high strength-weight ratios as indicative of good muscle-quality and good innervation and low strength-weight ratos as indicative of poor muscle-quality and poor innervation. Further investigation will be necessary before these factors can be separated; indeed it is quite within the bounds of physiological possibility that they are not separable; that excellence in one feature is always bound up with excellence in the other and vice versa.

Physical classification. For convenience in assigning individuals to categories in accordance with their physical strength, some simple scheme of classification is desirable. If our assumption is correct that the strength-weight ratio is an index of muscle-quality and of innervation it would suggest itself as a sound basis on which to work out such a classification. The limits of any such classification must be more or less arbitrary, at least until sufficient data are accumulated to enable them to be established by reference to a normal probability curve. If we are correct in our assumption that the averages of our present series are somewhat higher than would hold for adult males in general, the distribution of our cases about their average is not strictly comparable with the true distribution for adult males. We feel disposed, therefore, to suggest tentatively somewhat lower limits for our proposed classes than would be indicated by our data taken by themselves. The limits of the proposed classes are given in the subjoined table.

Class	*Strength-weight ratio*
A	more than 30
B	25.1–30
C	20.1–25
D	16.1–20
E	less than 16.1

The distribution of individuals in our series of 122 is as follows: class A, 17 (14 per cent); class B, 56 (46 per cent); class C, 47 (38 per cent); class D, 2 (2 per cent); class E, none. In general terms we would say that class A includes exceptionally strong men; class B, men of more than average strength; class C, men of average strength; class D, men of less than average strength; and class E, decided weaklings. Although our series included, according to this classification, no E men and only two D men, we think it altogether likely that a more representative

series, one in which clerks and factory hands were represented, would contain a due proportion of D men and a reduced percentage of A and B men. We are doubtful whether many healthy adult males will be encountered whose strength is so slight as to put them into the E class although our experience among the classes of the population in which marked physical weakness is likely to prevail is practically nil.

This classification, based on the strength-weight ratio, draws no distinction between small men of good quality and large men of equally good quality, although the latter will obviously be actually much more powerful than the former. For the practical purpose of assigning men to categories in accordance with their ability to achieve it would appear that some modification of the classification might well be made in which there is recognition of the importance of absolute muscular power as well as of good muscle-quality and good innervation. This end would be achieved if definite lower limits of strength were assigned to each class. Tentatively we would suggest the following limits: class A, 5000 pounds; class B, 4000 pounds; class C, 3000 pounds; class D, 1600 pounds. The practical effect of these absolute limits would be to require small men to show higher strength-weight ratios than large men, if they are to be placed in the higher classes. In no case would we reduce the limits suggested for the strength-weight ratios of the different classes. It would follow that a man weighing distinctly more than the average would have to show a strength well above the lower absolute limit of any given class in order to attain a strength-weight ratio that would admit him to it.

SUMMARY

1. The distribution of strength among the muscles in adult males is given (table 1).

2. The correlation between the strength of individual muscles and the entire strength is given (table 2).

3. Statistical evidence is presented showing that estimations of entire strength based on actual determinations of the strength of a few muscle-groups are valid.

4. Four pairs of muscle-groups: pectorals, forearm flexors, thigh adductors and thigh abductors are shown to correlate individually with entire strength to a satisfactory degree and to be also practically adapted for testing. They are selected, therefore, as constituting the "short" test.

5. The technique of the short test is presented in detail.

6. The summed strength of the muscles of the short test is shown to correlate well with the entire strength, the coefficient being 0.94 ± 0.01.

7. The adult males of this series are shown to have a higher average symmetry than the children of the former series; the average is 10.7 as compared with 16.7.

8. The ratio of strength to weight does not show the tendency to be constant in adult males that is seen in children. There is, however, a moderate correlation between strength and weight.

9. The factors influencing the strength-weight ratio are discussed. The conclusion is drawn that a high ratio signifies good muscle-quality and good innervation.

10. A physical classification, based primarily on the strength-weight ratio but modified to take some account of actual strength, is proposed.

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